II. *The* Bakerian *Lecture. Observations upon an unusual horizontal Refraction of the Air; with Remarks on the Variations to which the lower Parts of the Atmosphere are sometimes subject. By the Rev.* S. Vince, *A. M. F. R. S. and Plumian Professor of Astronomy and experimental Philosophy, in the University of Cambridge.*

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THE uncertainty of the refraction of the air near the horizon has long been known to astronomers, the mean refraction varying by quantities which cannot be accounted for from the variations of the barometer and thermometer; on which account, altitudes of the heavenly bodies which are not more than 5° or 6°, ought never to be made use of when any consequences are to be deduced from them. The cause of this uncertainty is probably the great quantities of gross vapours, and exhalations of various kinds, which are suspended in the air near to the earth's surface, and the variations to which they are subject; causes, of which we have no instruments to measure the effects which they produce, in refracting the rays of light. In general, the course of a ray passing through the atmosphere, is that of a curve which is concave towards the earth, the effect of which is to give an apparent elevation to the object; and thus the heavenly bodies appear above the horizon, when they are actually below it; but it will not alter the position of their parts, in respect to the horizon,

that is, the image of the highest part of the object will be uppermost, and the image of the lowest part will be undermost. The figures, however, of the sun and moon, when near the horizon, will suffer a change, in consequence of the refraction of the under limb being greater than that of the upper; from which they assume an elliptical form, the minor axis of which is perpendicular to the horizon, and the major axis parallel to it. But a perpendicular object, situated upon the surface of the earth, will not have its length altered by refraction, the refraction of the bottom being the same as that of the top.* These are the effects which are produced upon bodies at or near the horizon, in the common state of the atmosphere, by what I shall call the *usual* refraction.

But, besides the usual refraction which affects the rays of light, the atmosphere over the sea is sometimes found to be in a state which refracts the rays in such a manner as to produce other images of the object, which we will call an effect from an *unusual* refraction. In the Phil. Trans. for 1797, Mr. HUDDART has described some effects of this kind, which he has accounted for by supposing that, from the evaporation of the water, the refractive power of the air is not greatest at the surface of the sea, but at some distance above it; and this will solve, in a very satisfactory manner, all the phænomena which he has observed. But effects very different from those which have been described by Mr. HUDDART are sometimes found to take place. These I had an opportunity of observing at Ramsgate, last summer, on August the first, from about half an hour after four o'clock in the afternoon till between seven and eight. The day had been extremely hot, and the evening was very

* See my *Complete System of Astronomy*, Art. 194.

sultry; the sky was clear, with a few flying clouds. I shall describe the phænomena as I observed them with a terrestrial telescope, which magnified between 30 and 40 times; they were visible, however, to the naked eye. The height of the eye, above the surface of the water, at which most of the observations were made, was about 25 feet; some of them, however, were made at about 80 feet from the surface; and it did not appear that any of the phænomena were altered from varying the height of the eye, the general effect remaining the same.

The first unusual appearance which I observed, was that which is represented in Tab. I. fig. 1. Directing my telescope at random, to examine any objects which might happen to be in view, I saw the top of the masts of a ship A, above the horizon, *x y*, of the sea, as shown in the figure; at the same time also, I discovered in the field of view, two complete images, B, C, of the ship in the air, vertical to the ship itself, B being inverted, and C erect, having their hulks joined. The phænomenon was so strange, that I requested a person present to look into the telescope, and examine what was to be seen in it, who immediately described the two images, as observed by myself; indeed they were so perfect, that it was impossible we could differ in our description. Upon this, I immediately took a drawing of the relative magnitudes and distances of the ship and its images, which, at that time, were as represented in the figure, as near as it was possible for the eye to judge; and it was very easy to estimate them to a very considerable degree of accuracy. As the ship was receding from the shore, less and less of its masts became visible; and, continuing my observations, in order to discover whether any, or what variations might take place, I found that, as the ship descended, the images B, C

ascended; but, as the ship did not sink below the horizon, I had not an opportunity of observing at what time, and in what order, the images would have vanished, if the ship had so disappeared.

Being desirous of seeing whether the same effect was produced upon the other ships which were visible, I directed my telescope to another ship A, (fig. 2.) whose hulk was just in the horizon $x\,y$; when I observed a complete inverted image B, the main-mast of which just touched that of the ship itself. In this case, there was no second image as before. The ship A moving upon the horizon, B continued to move with it, without any variation in its appearance.

The next ship which I directed my telescope to, was so far on the other side of the horizon $x\,y$, as just to prevent its hulk from being seen, as is represented by A, (fig. 3.). And here I observed only an inverted image of part of the ship; the image y of the topsail, with the mast joining that of the ship, the image x of the top a of the other mast, and the image z of the end c of the bowsprit, only appearing at that time. These images would suddenly appear and disappear very quickly after each other; first appearing below, and running up very rapidly, showing more and less of the masts at different times, as they broke out; resembling, in the swiftness of their breaking out, the shooting out of a beam of the Aurora borealis. As the ship was descending on the other side of the horizon, I continued my observations upon it, in order to discover what changes might take place; when I found, that as it continued to descend, more of the image gradually appeared, till at last the image of the whole ship was completed, with their main-masts touching each other; and, upon the ship descending lower, the image

and the ship separated; but I observed no second image, as in the first case; a second image, however, might probably have appeared, if the ship had continued to descend.

Upon moving my telescope along the horizon, in order to examine any other ships which might be in sight, I observed, just at the horizon *x y*, (in fig. 4.) the top *a* of the mast of a ship; and here an effect was observed, which had not been before discovered; for there was an inverted image B, vertical to *a*, an erect image C, both of them very perfect and well defined, and an image *v w* of the sea between them, the water appearing very distinctly. As the ship was coming up towards the horizon, I continued to observe it, in order to discover the variations which might follow, and found, that as the ship approached the horizon, the image C gradually disappeared, and at last it vanished; after that, the image *v w* of the sea disappeared; and during this time the image B descended; but the ship did not rise so near to the horizon as to bring the main-masts together. Had I directed my telescope to the same point of the horizon a little sooner, I should have seen the two images, before the ship itself was visible. In fact, the images were visible, when the whole ship was actually below the horizon; for, from the very small part of the mast which was at first visible, that part must then have been below the horizon, and appeared above it by the usual refraction; the altitude of *a*, above the horizon, having then been much less than the increase of altitude which arises from the common horizontal refraction. The discovery of ships in this manner might, in some cases, be of great importance; and, on such occasions, it might be worth while to appoint proper persons to make observations for that purpose.

The cliffs at Calais being very visible, I directed my telescope towards them, in order to examine whether there was any thing unusual in their appearance; when I observed an image of the cliffs, above the cliffs themselves, together with an image of the sea separating them, as is represented in fig. 5.; in which, *x y* represents the horizon of the sea, AB the cliffs, *a b* their image, and *v w* the image of the sea between them: the depth of *a b* was much less than that of AB. It is probable, however, that *v w* might not be the image of the sea immediately adjoining to the cliffs, but a partial elevation of the sea at some distance from them; and that the image *v w* might intercept some part of the image *a b*, which would otherwise have been visible: we must not therefore conclude, that the image *a b*, so far as it appeared, was less than the corresponding part of the object. From the memorandums which I made at the time of observation, I do not find that I examined the appearance of the cliff AB, and its image *a b*; which, had there at that time been any striking marks in them, would have determined whether the object and its image were of the same magnitude. The image *a b* was, however, erect; the boundaries on the top of AB and *a b* agreeing together. Having examined this for some time, and taken a drawing of the appearance, during which I could discover no variation, I directed my telescope to other objects; and, upon turning it again to the same cliffs, after the space of about six or seven minutes, the images *a b* and *v w* were vanished; but, examining them again soon after, the images were again visible, and in every respect the same as they appeared before. A short time after, they disappeared, and did not appear any more.

Soon after the above appearances, I observed a ship C, with

the hulk below the horizon *x y*, passing by the same cliffs AB; an inverted image D of which appeared against the cliffs, as represented in fig. 6. The ship was in motion, and remained at the same distance on the other side of the horizon: I continued my observations upon it till it had passed the cliffs for a considerable distance, but there was no change of appearance. The cliffs were illuminated by the sun, and appeared very distinctly; but there was no image above, as in the last case.

Continuing to observe the same cliffs AB, fig. 7, I soon after discovered two partial elevations *m*, *n*, of the sea, by the unusual refraction; they changed their figures a little, and disappeared in the place where they first appeared, and were equally distinct in every part.

About this time, I observed a very thick fog coming upon the horizon from the other side, rolling upon it with a prodigious velocity; curling as it went along, like volumes of smoke sometimes out of a chimney. This appeared several times. I conclude, therefore, that there was a considerable fog on the other side of the horizon.

The last phænomenon which I observed was that which is represented in fig. 8; where *x y* represents the horizon, *a b* two partial elevations of the sea, meeting at *c*, and continued to *d*; *e*, another partial elevation of the sea, of which kind I observed several, some of which moved parallel to the horizon, with a very great velocity. I conjecture, therefore, that these appearances were, in part at least, caused by the fog on the other side of the horizon. For, though I did not at the same time see the motion of these images and that of the fog, yet, from memory, I judged the motions to be equal; and they were also in the same direction. A fog which, by producing an unusual refrac-

tion, might form these images, would, by its motion, produce a corresponding motion of the images.

I have here described all the different phænomena which I observed from the unusual refraction, of most of which I saw a great many instances. Every ship which I observed on the other side of the horizon of the sea, exhibited phænomena of the kind here described, but not in the same degree. Of two ships which, in different parts, were equally sunk below the horizon, the inverted image of one would but just begin to appear, whilst that of the other would represent nearly the whole of the ship. But this I observed, in general, that as the ship gradually descended below the horizon, more of the image gradually appeared, and it ascended; and the contrary, when the ships were ascending. Upon the horizon, in different parts, one ship would have a complete inverted image; another would have only a partial image; and a third would have no image at all. The images were in general extremely well defined; and frequently appeared as clear and sharp as the ships themselves, and of the same magnitude. Of the ships on this side of the horizon, no phænomena of this kind appeared. There was no fog upon our coast; and the ships in the Downs, and the South Foreland, exhibited no uncommon appearances. The usual refraction at the same time was uncommonly great; for the tide was high, and at the very edge of the water I could see the cliffs at Calais a very considerable height above the horizon; whereas they are frequently not to be seen in clear weather from the high lands about the place. The French coast also appeared both ways, to a much greater distance than I ever observed it at any other time; particularly towards the east, on which part also the unusual refraction was the strongest.

During the remainder of my stay at Ramsgate, which was about five weeks, I continued daily to examine all the ships in sight; but I discovered no phænomena similar to those which I have here given a description of. The phænomenon of the ship observed by Mr. HUDDART, differed altogether from those above described, as the inverted image which he observed was below the ship itself. An appearance of this kind I observed on August the 17th, about half an hour after three o'clock in the afternoon, of which fig. 9. is a representation. The real ship is represented by A, and the image by B; *er*, *mv*, the hulks; *s t* the flag, and *w x* its image, just touching it, with the sea *x y* below. Between the two hulks, some faint dark spots and lines appeared, but I could not discover what they were the representatives of. The vessel, at the time of this appearance, was not quite come up to the horizon; and, as it approached it, the image gradually diminished, and totally disappeared when the ship arrived at the horizon.

It remains now, that we inquire into the causes which might produce the very extraordinary effects which have been above related. From the phænomena, we are immediately led to the nature of the path of the rays of light to produce them; and we may conceive, that the air may possibly be in such a state as will account for the unusual tract which they must have described. For, let *b z* (fig. 10.) be the surface of the sea; *a b* an object; E the place of the eye; *a r* E, *b s* E, the progress of two rays, by the usual refraction, from the extreme parts of the object to the eye; to these curves draw the tangents E *a'*, E *b'*, and *a' b'* will be the image of the object, as usually formed. Now, if we take the case represented in fig. 4, let *a'' b''* represent the inverted image, and *a''' b'''* the erect image; join *a''* E,

a''' E, and b'' E, b''' E, and these lines must respectively be the directions of the rays entering the eye from a and b, in order to produce the images $a''\,b''$ and $a'''\,b'''$; hence, these lines must be tangents at E, to the curves which are described by the rays of light; let therefore $a\,n$ E, $a\,m$ E, $b\,v$ E, $b\,w$ E, be the curves described. We have therefore to assign a cause which may bring rays passing above the rays $a\,r$ E, $b\,s$ E, to the eye at E. Now, if there were no variation of the refractive power of the air, a ray of light passing through it would describe a straight line; therefore, the curvature of a ray of light passing through the atmosphere, depends upon the *variation* of the refractive power of the air. If, therefore, we suppose the air lying above $a\,r$ E, to vary quicker in its refractive power than the air through which $a\,r$ E passes, the curvature of a ray proceeding above that of $a\,r$ E, will be greater than the curvature of $a\,r$ E; and upon this principle we may conceive that a ray may describe the curve $a\,n$ E: and, in like manner, if a quicker variation of refractive power should take place above the curve $a\,n$ E, than in that curve, a third ray may describe the curve $a\,m$ E. The same may be said for the rays $b\,v$ E, $b\,w$ E, diverging from b. The alterations of the refractive power may arise, partly from the variations of its density, and partly from the variations of its moisture; and the passage of the rays through the boundary of the fog may there suffer a very considerable refraction; for, from the motion of the fog, and that of the images abovementioned, I have no doubt that the fog was a very considerable agent in producing the phænomena. When all the causes co-operate, I can easily conceive that they may produce the effects which I have described. If the cause should not operate in the tract of air through which the curves

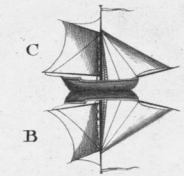


Fig. 1.

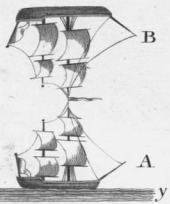


Fig. 2.

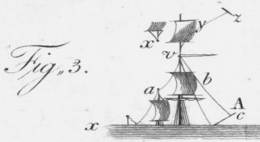


Fig. 3.

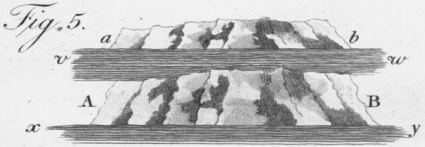


Fig. 5.

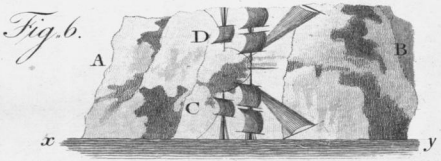
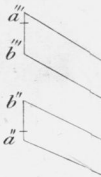


Fig. 6.



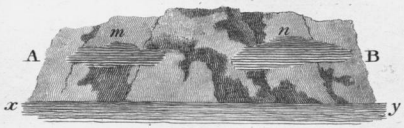


Fig. 7.

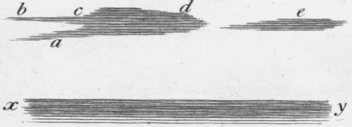


Fig. 8.

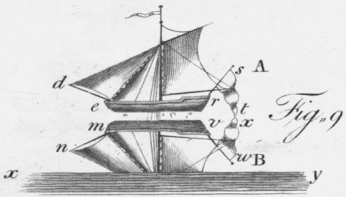
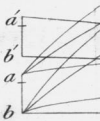


Fig. 9.



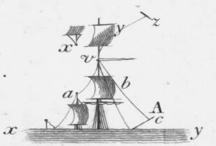


Fig. 3.

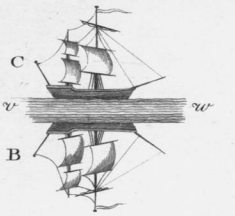
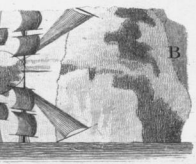


Fig. 4.



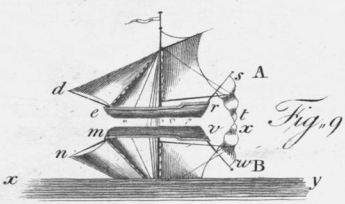


Fig. 9.

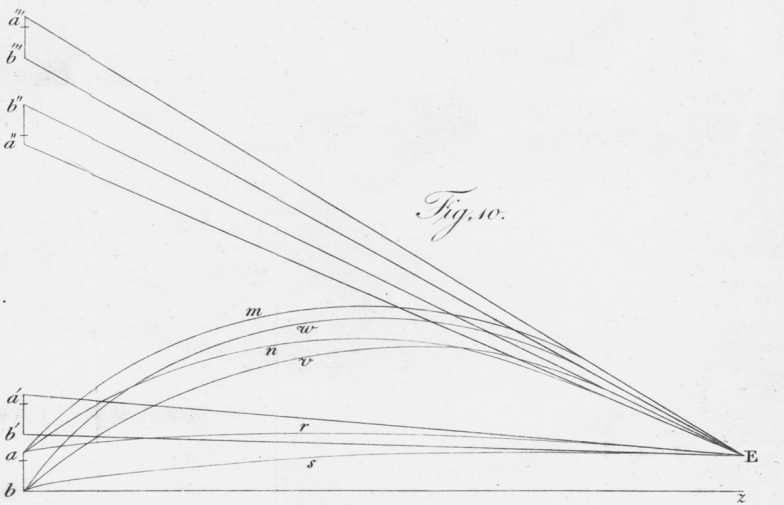


Fig. 10.

a n E, *b v* E pass, but should operate in the tract through which *a m* E, *b w* E pass, an erect image would be visible, but there would be no inverted image; and, should it operate in the latter case, but not in the former, there would be only an inverted image.

As the phænomena are very curious, and extraordinary in their nature, and have not, that I know of, been before observed, I have thought proper to lay a description of them, with all the attending circumstances, before the Royal Society. They appear to be of considerable importance; as they lead us to a knowledge of those changes to which the lower parts of the atmosphere are sometimes subject. If, when these phænomena appear, a vessel, furnished with a barometer, thermometer, and hygrometer, below, and also at the top of the mast, were sent out to pass below the horizon and return again, and an observer at land, having like instruments, were to note, at certain intervals, the situation and figure of the images, it might throw further light upon this subject, and lead to useful discoveries respecting the state of the atmosphere, from a conjunction of the causes which affect these instruments.